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DETECTION OF OIL IN SEWERS

Ditmar H. Bock, et al

Calspan Corporation

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DETECTION OF OIL IN SEWERS

by

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Project No. 11020 DJG

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16. ABSTRACT

Methods capable of detecting oil present as a pollutant in waste water were selected which are capable of measuring quantities of oil from as small as those in a surface active film to massive accumulations. Detection techniques for both thick and thin oil deposits were studied and systems incorporating the most promising ones were developed and tested. It was found that more techniques can be adapted to the thick oil than to the thin oil detection problem because thick oil can be measured by electricial and thermal conductivity devices which require little maintenance in sewer use whereas detectors of small amounts are somewhat less suited to the sewer environment. The most promising techniques developed used RF and heat conductivity sensors for the detection of massive oil accumulations from a few millimeters to several meters thick and ultraviolet transmission sensors for the detection of dispersed oil over the range of 5 to 10,000 parts per million. The resulting instrumentation was tested in a sewer environment and found to be capable of unattended operation for periods ranging from a week to several months. The instrumentation was combined with telemetry to permit readout at a remote central location.

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FOREWORD

The multi-media character of pollution resulting from the extraction, processing, conversion, and utilization of energy and mineral resources and from industrial processing and manufacturing operations requires a research approach which recognizes the complex environmental impact of these operations.

The Industrial Environmental Research Laboratory-Cincinnati utilizes a multidisciplinary approach in the development and demonstration of technologies to effectively deal with the pollution associated with these operations. The Laboratory assesses the environmental impacts of industrial and energy-related activities and identifies, evaluates and demonstrates control alternatives.

This report is a product of the above efforts. It describes studies conducted to detect oil present as a pollutant in waters such as sewer flows. This study is part of an effort of our oil and hazardous chemical spills program to develop control technology for oil discharges.

David G. Stephan
Director
Industrial Environmental Research Laboratory-Cincinnati

ABSTRACT

Methods capable of detecting oil present as a pollutant in waste water were selected which are capable of measuring quantities of oil from as small as those in a surface active film to massive accumulations. Detection techniques for both thick and thin oil deposits were studied and systems incorporating the most promising ones were developed and tested. It was found that more techniques can be adapted to the thick oil than to the thin oil detection problem because thick oil can be measured by electrical and thermal conductivity devices which require little maintenance in sewer use whereas detectors of small amounts are somewhat less suited to the sewer environment. The most promising techniques develcped used RF and heat conductivity sensors for the detection of massive oil accumulations from a few millimeters to several meters thick and ultraviolet transmission sensors for the detection of dispersed oil over the range of 5 to 10,000 parts per million. The resulting instrumentation was tested in a sewer environment and found to be capable of unattended operation for periods ranging from a week to several months. The instrumentation was combined with telemetry to permit readout at a remote central location.

This report was submitted in fulfillment of Program Number 11020 DJG, Grant Number WPRD 263-01-68 by Calspan Corporation (formerly Cornell Aeronautical Laboratory, Inc.) under the partial sponsorship of the U.S. Environmental Protection Agency.

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CONCLUSIONS

Several techniques for detecting quantities of oil ranging from monomolecular films to massive accumulations were developed and tested. A device based on the ultraviolet transmission characteristics of oil is capable of sensing dispersed oil over the range of 5 to 10,000 parts per million or surface layers ranging in thickness from a few microns to about one millimeter. RF and heat conductivity sensors were developed which can detect massive oil accumulations from a few millimeters to several meters thick. All three types of devices were tested in sewers and were found to remain functional for periods of months, with some maintenance required for the more sensitive sensors at intervals of weeks. The sensors were compatible with narrow-band, low-duty-cycle telemetry which permits central readout of measurements from many sensors. The estimated cost of these instruments is low, ranging from less than $100 per sensor for the conductivity meters to a few hundred dollars for the UV transmission sensor.

RECOMMENDATIONS

It is recommended that a program be undertaken to demonstrate the utility of sensors to localize sources of oil and abate the dumping of oil in municipal sewers. A network of 30 to 40 oil detectors, coupled with alarm circuits and sampling devices, should be installed at strategic locations in a metropolitan sewer system with provisions for recording oil concentrations at each detector station, telemetering the occurrence of oil spills to a control center, and taking fluid samples upon detection of a spill. In addition to the ultraviolet transmission sensor described in this report, gasoline vapor and other detector devices might also be installed at some of the locations.

INTRODUCTION

Oil pollution has plagued not only coastal areas, but also inland lakes and rivers which are subjected to oil inputs from industries, service stations, and consumers. The inputs from large industries, especially the oil transportation trade, tend to be fairly large and visible and thus subject to policing. Discharges from small local industries and consumers usually enter sewage systems and prove to be a problem in the treatment process. They are occassionally discharged into open water either because of overflow conditions or because the treatment plant is not able to cope with them. These discharges are very difficult to police and it would be useful if they could be detected in sewers in a fashion which would permit identification of the source of the oil discharge. A reasonable number of oil monitors in each city appear to be adequate for this purpose. For example, in the City of Buffalo, it has been estimated that some 60 sensors, strategically placed, could locate most sources.

In May 1968 the City of Buffalo made application to the Federal Water Pollution Control Administration for a Research and Development Grant for preventing and eliminating oil pollution of the Buffalo River under the provisions of the "Clean Water Restoration Act of 1966." On 24 July 1968 the City of Buffalo accepted a Federal Research and Development Grant (WPRD 263-01-68) for $552,895.00, or 75% of eligible costs, whichever is less. Twenty-five percent of the eligible costs have been provided by the City of Buffalo, the Buffer Sewer Authority, the County of Erie, and the New York State Health Department in the form of either direct cash contributions or in-kind services. On 18 October 1968 a contract was negotiated with Cornell Aeronautical Laboratory, Inc. (now Calspan Corporation) of Buffalo, New York to provide the research, engineering, and development support required for the program (Calspan Corporation is the new name for Cornell Aeronautical Laboratory. Because this report was completed prior to the date of our name change (November 17, 1972), Cornell Aeronautical Laboratory nomenclature has been retained in this report).

The overall objective of the program was to prevent oil pollution of the Buffalo River. Specific objectives of the program were:

1) To develop, utilize and evaluate equipment and techniques for containing and removing oil in the river, including floating mechanical barriers and pneumatic barriers for preventing the movement of surface oil, oil skimmers, debris booms, and a boat containing oil and debris removal equipment
2) To develop instrumentation for detecting oil in sewers
3) To evaluate means for trapping oil in sewers
4) To devise methods for sampling oil to determine its concentration in the river, and to develop methods for analyzing the collected samples to determine their sources

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Specific aspects of the program are described in detail in four separate topical reports and summarized in a summary report. This topical report covers the detection of oil in sewers. The other three reports cover The investigation of inverted siphons for trapping oil, the evaluation of a pneumatic barrier for oil containment, and oil sampling and analysis for spills in water-courses.

Pollutant oils, usually petroleum products and sometimes greases of biological origin, are easily detected by odor, appearance or feel. They are effectively separated from other substances by solvent extraction and separated into fractions by distillation. A given mixture found as a pollutant can frequently be matched against a sample from the pollution source by multiple solvent extraction (Reference 1) or by infrared (IR) absorption spectrography. Although the latter technique can be combined with a particularly sensitive sampling method (Reference 2), it, and most other current detection techniques for pollutant oils, are suitable for laboratory use but the size, cost and complexity of requisite equipment precludes its remote, unattended operation in sewers.

Fairly simple oil sensors must be distributed throughout the sewer system before pollutant oil, detected at one or a few locations, can be analyzed and thereby traced to its source. Instruments for this purpose should meet a number of criteria but of utmost importance are sensitivity and reliability. The instrument is intended to save manpower spent in sampling and analysis, and therefore, should not merely switch the type of employees needed from maintenance crews and chemists to electronic technicians. The instrument should be inexpensive to compensate for replacement costs due to unforeseeable damage, to permit multiple installations, and to remove the need for maintenance which is usually not pleasant and may prove to be a biological hazard. Also, if the instrumentation is emplaced in a manner which permits monitoring at a central location, it will help to conserve manpower.

Very few instruments capable of sensing oil in a sewer even under special conditions are now commercially available. Two companies (Heath Company, Benton Harbor, Michigan and Mine Safety Appliances, Pittsburg, Penn.) manufacture fuel vapor detectors (Model MI-25 and Model 24, respectively) which respond to gasoline vapors and these devices have been used in sewer pipes (Reference 3). Bull and Roberts, Murray Hill, N.J., "Aqualert" and Bailey Meters and Controls, Croydon CR94HE, England manufacture instruments for detection of oil in boiler water, which might find use in the sewer application. However, as indicated by Dr. R. Norris of CITCO in a private communication, these detectors are subject to giving false indications at the level of fouling encountered in sea water and in sewers. A modification of this type of detector which circumvents the fouling problem for a useful time was developed in this program (see Thin Film Detectors). An optical surface sensor (Model 1479) for detecting oil on water was announced by the Hallikainen Company of Richmond, Calif. during the course of this study but it proved impossible to ascertain the characteristics of the sensor.

During this study, detection techniques for thick accumulations and thin films of oil were studied and several promising oil detectors were developed and tested in sewers. Many more techniques can be adapted to the thick oil detection problem than to the thin oil detection problem because thick oil can be measured by electrical and thermal conductive devices which are well suited for sewer use. Detectors of small amounts (i.e., thin oil films) are more susceptible to fouling and therefore, less suited for use in sewers.

THICK OIL DETECTORS

It proved possible to evaluate bulk oil sensors in a sewer by means of an inverted siphon structure (Figure 1) which is used to carry sanitary sewage under a storm sewer and can collect a quantity of several hundred gallons of oil. Careful tests of the oil input, output and storage in this structure showed that it is capable of collecting about one-sixth of the oil (as measured by chloroform-extraction) carried in the sewage. While this collection efficiency is not sufficient to relieve the loading on a sewage disposal plant, it proved extremely useful for metering purposes. At the present time, the oil is pumped out when it reaches a depth of about eight feet (2.4 m, equivalent to about 3000 liters) and the rate of rise of the oil layer is a convenient measure of input. Studies to improve the trapping efficiency of future designs of inverted siphons are planned.

Oil accumulations in the manholes connecting to the inverted siphon had been measured for several years by means of an assembly of wood rods coated with a dyed salve which changes color in water. This rod assembly, upon immersion to the bottom of the manhole, shows three zones. At the top, above the oil level, the rod is clean, Below the oil level, the dye is discolored. In the intermediate region, which indicates the thickness of oil, the sticks are sullied but the dye preserves its initial color. A measurement by this technique required two people and consumed about forty minutes, including the time spent for cleanup. Since measurement of electrical conductivity was expected to be quicker and simpler, a number of conductivity sensors were studied in the laboratory. Included was an assembly of wires spaced at intervals of about two centimeters. Conduction between these wires and a common, lower electrode, measured either with direct or low frequency alternating current, disappeared as soon as oil coated the electrodes and did not reappear within a reasonable time (~ 1 week). Next an assembly of a VHF (30...100 MHz) oscillator and a pair of Lecher wires was tested (Figure 2). This device proved to be an excellent indicator of small wave heights, once the wires were enclosed in the shield as shown in Figure 2, but no simple method of admitting the oil in the presence of leaf-like obstructions was found. In addition, extreme variations in frequency were encountered with oil layers varying from six inches to several feet. To alleviate this problem, much of the inductance used to tune the oscillator was lumped in the float supporting the sensor. Although this approach was relatively satisfactory (tuning rate dropped to 40 kHz/cm), simpler techniques, described in the following, were devised.

RF CONDUCTIVITY SENSOR

It was found that an LC oscillator, at a frequency of about 10 MHz, would be loaded by the conductivity of the fluid surrounding its coil. The coil could be wound with stainless steel wire or tubing and had a very good life-span in sewage and oil. In contrast to the previously

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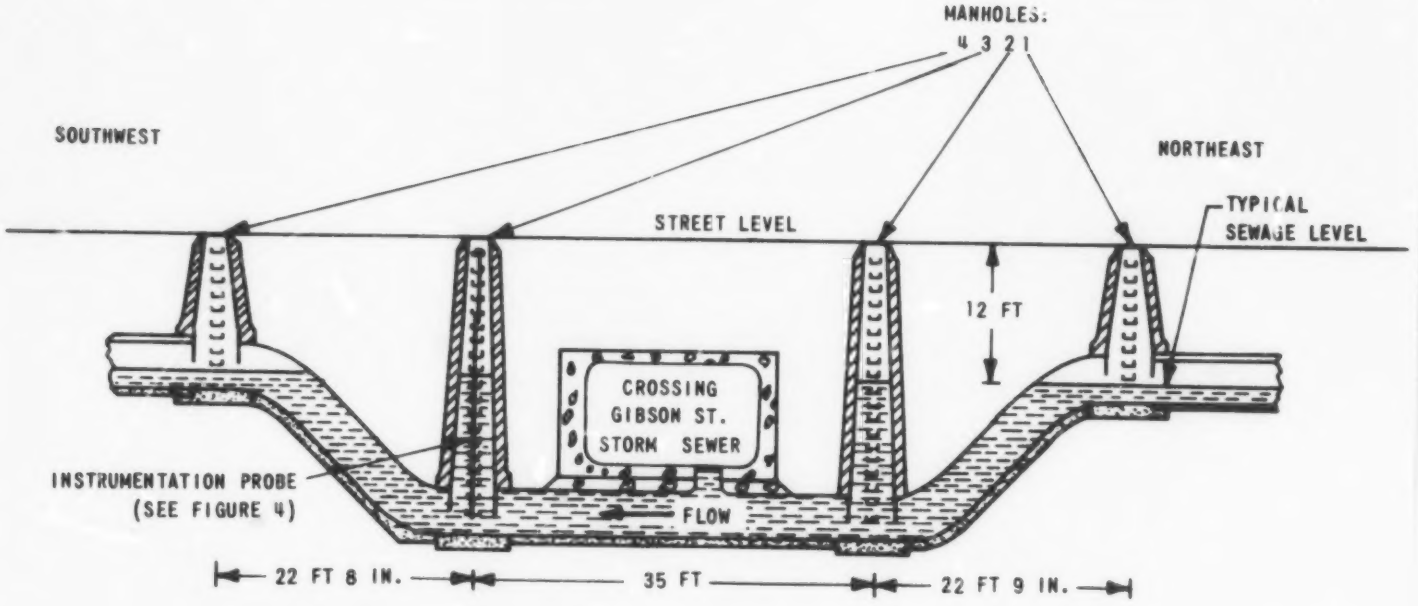

Figure 1 CROSS SECTION OF INVERTED SIPHON

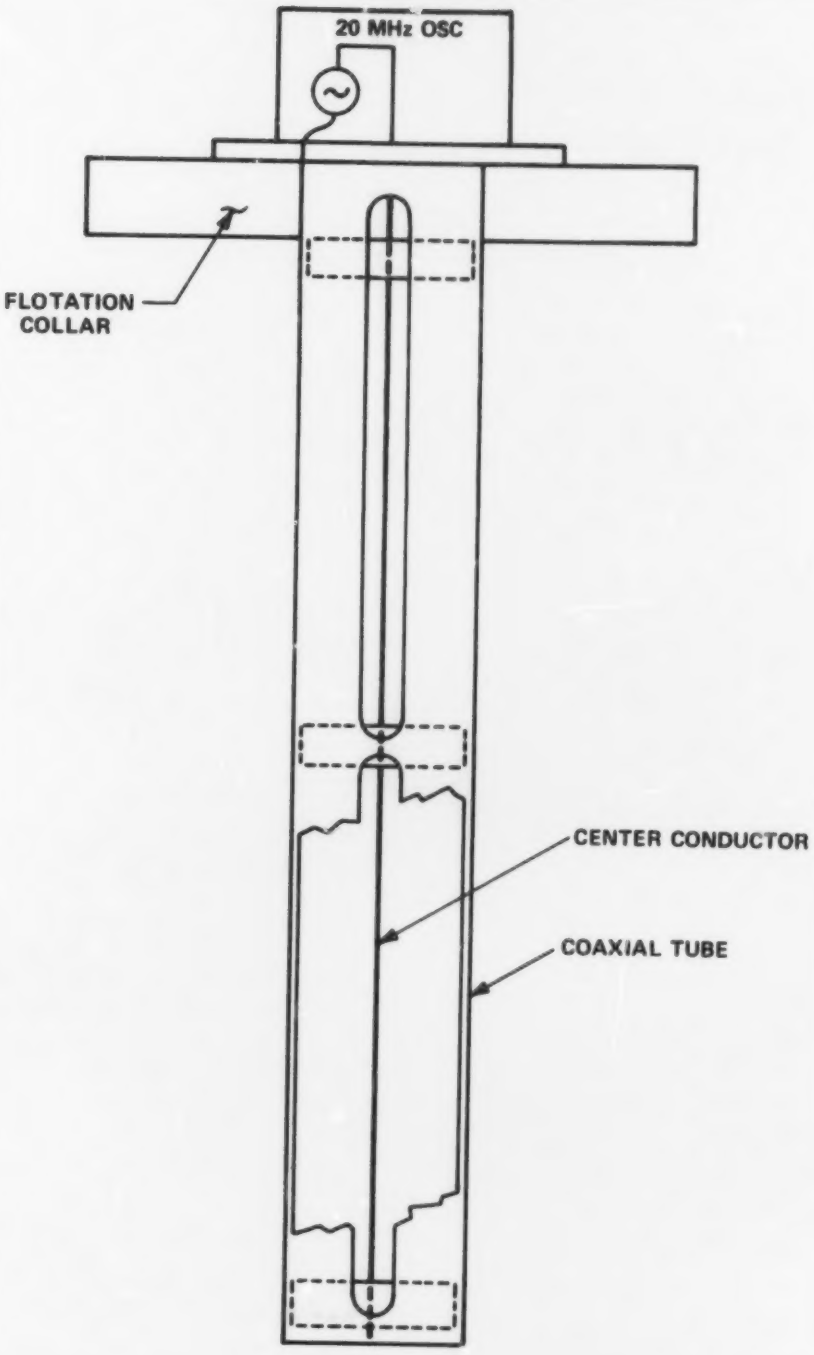

Figure 2 LECHER WIRE OIL DEPTH GAUGE

discussed sensors, this device (Figure 3) was not disabled by leafy materials. In this device, the sensing coil is part of a transistor Colpitts oscillator biased with a negative feed back circuit to reduce the effect of variations in the common emitter current gain (h_{FE}) of the transistor. The circuit, depicted in Figure 3, provides a base current which is approximately proportional (if V_{BE} is ignored) to collector voltage. The latter is given by

$$e_c = e - (h_{FE}+1) r i_b$$

$$i_b \approx \frac{e_c}{R}$$

By choosing the ratio (R/r) approximately equal to the geometric mean of h_{FE} for the class of transistors to be used, the circuit (in the absence of oscillation) is biased to operate under Class A conditions for a large range of current gains. For example, for h_{FE} between 30 and 300, the collector voltage will vary from about 75 percent to 25 percent of the supply voltage. Oscillation is initiated by positive feedback through the pi-network consisting of C1, L, and C2. Two other capacitors (C3 and C4) isolate the stainless steel coil from the DC bias voltages of the transistor circuit. When the coil is surrounded by conductive fluid, part of the power generated at the collector is absorbed by the fluid and is therefore not delivered to the base (The conductivity of sewer water is fairly high and exceeds that of tap water even in heavy rain. Local tap water is several orders of magnitude more conductive than distilled water which loads this device slightly). The base bias voltage, generated by rectifying the AC signal across C2, decreases in the presence of the conducting fluid. This voltage is sensed and amplified by another transistor (Q2) and the resulting signal, a current varying from zero to one millampere, serves as an indication of the loading due to the fluid surrounding the coil.

All components of this circuit, except for the coil, are mounted on a printed circuit board (Figure 4) which was dimensioned to fit into the bore of one inch polyvinylchloride (PVC) pipe (34 mmOD, 23 mmID). Oblong slots (23 mm x 9 mm) were machined into a section of this pipe at intervals of 30 cm (1 foot) and a coarse thread of about 10 turns in 30 mm was cut into the outside of the pipe to accommodate the stainless steel coil. The assembled circuits were installed through the slots, connected to the coil, the ends of which were coated with silver solder to facilitate soft soldering, and encapsulated with hard epoxy. Sections of the pipe between sensors which contained wires to the circuits were filled by generating polyurethane foam in the pipe, thereby waterproofing the entire assembly (Figure 5).

OTHER TECHNIQUES

A number of other sensors of fairly deep oil were investigated. The most successful of these, and one which is capable of sensing layers as thin as one centimeter (0.4 inch), was tested in the inverted siphon.

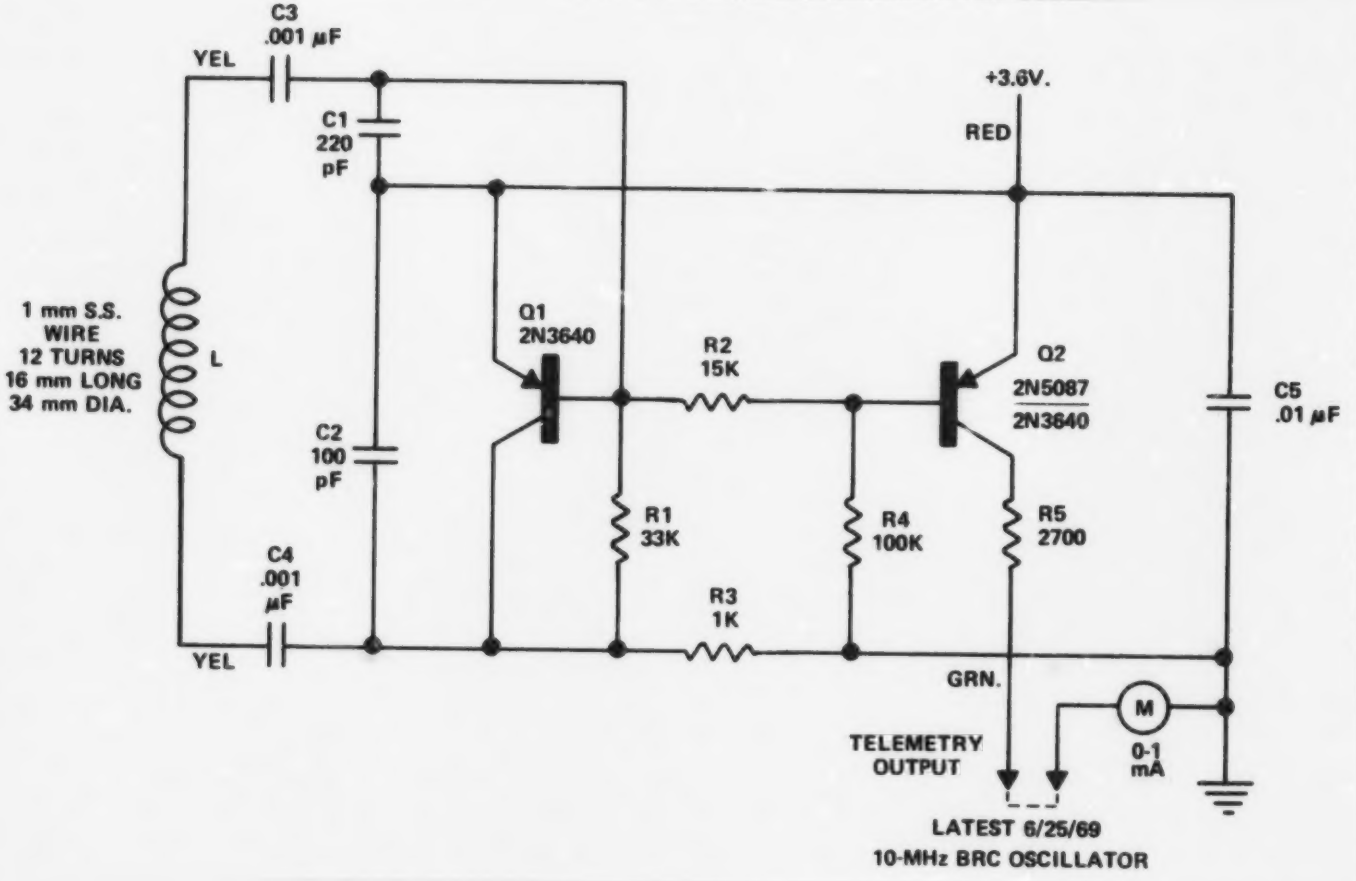

Figure 3 SCHEMATIC OF 10-MHz OSCILLATOR

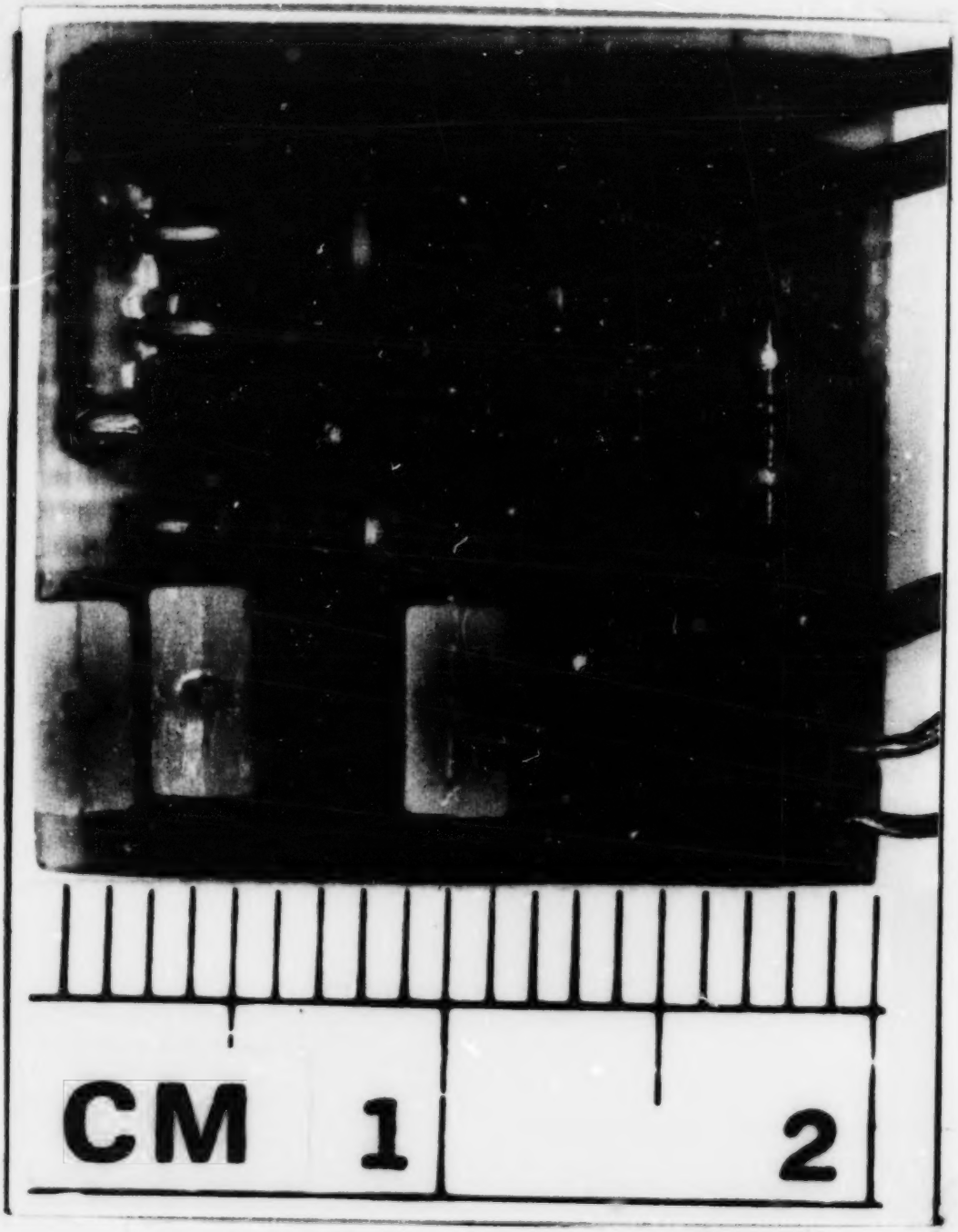

Figure 4 RF CONDUCTIVITY SENSOR - CIRCUIT BOARD

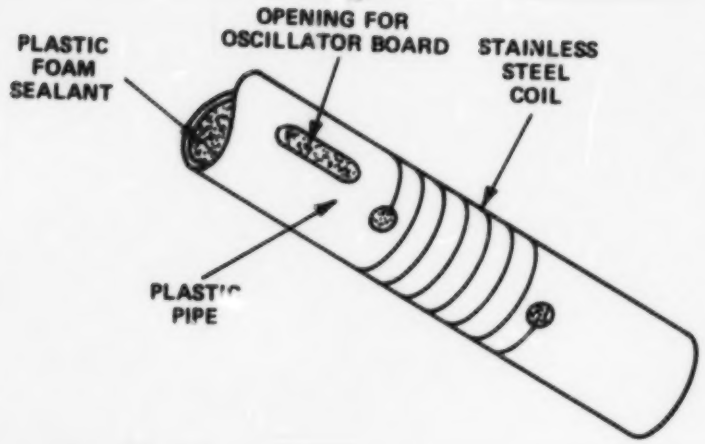

Figure 5 RF CONDUCTIVITY SENSOR-PROBE

It was found to be resistant to almost all fouling problems. It consisted of a thermistor (Fenwal Type KB21J1) coated with a thin cover of formvar varnish and mounted in a shroud which reduced flow around the sensor (Figure 6). The thermistor was connected in series with a 6 V (AC or DC) source and an incandescent lamp (GE#47), the voltage across which was measured by a voltmeter. This circuit is quite familiar as a fluid level sensor, but shows remarkable sensitivity to differences in the heat transfer characteristics of oil and water. In a typical device, the voltage across the lamp varies from 5 V in air to 3.5 V in oil (SAE30 motor oil) to 2.5 V in water. This sensor is most useful when the oil layer is not visible from the manhole. The observer lowers the probe until the oil-air interface is sensed, marks the cable at the edge of the manhole and continues lowering to the oil-water interface where the cable is marked again. The distance between marks indicates the oil depth. An attempt was made to mount this sensor between the hulls of a catamaran-like float, and to sense oil in a creek behind a floating barrier. The surface tension of the oil caused it to spread upstream for a great distance without permitting it to accumulate to a thickness of about 5 mm which is needed to activate the sensor.

TESTS IN SEWERS

Several configurations of the bulk oil detectors were tested in sewers. A single RF conductivity sensor, in a pipe approximately 20 cm long, which is weighted with lead and attached to a length of PVC-covered three-wire cable, is used by personnel of the Buffalo Sewer Authority.

Figure 6 THERMISTOR SENSOR MOUNT

An assembly of these sensors, alternated at intervals of one foot with thermal sensors, was installed in a manhole of the inverted siphon shown in Figure 1. Readings were taken by connecting a multipin connector, which was usually kept in a plastic bag, to a "readout box" which was brought to the site. Although this arrangement was no more convenient than the portable probe, it was useful in testing whether or not the sensors would survive exposure in the sewer and properly differentiate between oil and sewage even after repeated, alternate exposure to both.

Comparisons between the permanently installed assembly, the portable probes and the dyed stick sensor over a period of two months showed consistent behavior. Excellent agreement (±5%) was observed between the indicated volume of oil, estimated from oil depth and the cross section of the manhole, and the volume removed during periodic pumping. Before each pumping, solid waste materials had to be removed by clamming. The clam eventually sheared the PVC pipe at a number of places, and although the teflon-coated wires in the pipe were not damaged, the assembly became unsightly (Figure 7) after a few months and was replaced with another which could easily be removed before clamming.

An assembly of eight RF conductivity sensors was mounted on a PVC pipe 3 m long, equipped at the upper end with a polyurethane foam float enclosed in a pair of cake pans for impact protection (Figure 8). This assembly was connected to a sampling circuit and audio frequency modulator (Reference 4) at the top of the manhole. A pair of shielded wires was run through a conduit from a power pole at the edge of the street. One wire carried DC power to recharge NiCd batteries in the manhole box while the other carried audio signals to a utility box mounted on the pole. There, a power supply and Citizen's Radio Service (Class C, Model Control) transmitter, equipped with a timer which activates it for several seconds each hour, permitted signalling of the oil level to a monitoring facility several kilometers away at Cornell Aeronautical Laboratory. Because of the extensive use of citizen's band (CB) model control channels by CB voice operators, some interference was encountered, but approximately tenfold repetition of the sampling sequence permitted reliable readings. (This radio service is not suitable for extensive telemetry and another band allocation would be required if a number of stations were operative.) The signals were received with a communications receiver, decoded with an audio FM demodulator and recorded on a strip chart recorder. The recorder was started by the presence of an RF signal. The floating sensor and its associated telemetry operated satisfactorily for more than four months, at which time one of the coils separated from the pipe. Corrosion of the stainless-steel to solder joint by leakage into the encapsulation is believed to have caused this fault. This type of installation is economic when oil can be trapped in layers more than one decimeter (4-inches) deep. The cost is primarily that of connecting to the manhole from the side of the street.

Figure 7 THERMAL AND RF BULK OIL SENSOR ASSEMBLY

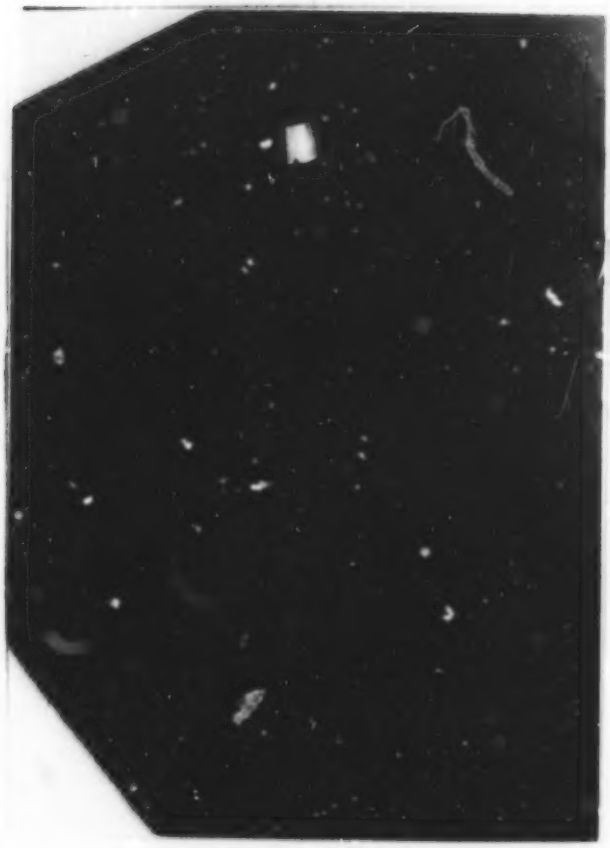

Figure 8 FLOATING BULK OIL SENSOR

THIN FILM DETECTORS

Oil can be found in slicks ranging from monomolecular films about 10 nanometers thick to ones with a thickness of several millimeters. When the thickness of the layer is of the order of the wavelength of light (about 0.5 micron), interference fringes are seen. Attempts to utilize this effect in an automatic sensor proved futile because it involves recognition of a pattern which is easily masked by waves and debris on the surface. Index of refraction measurement at the Brewster angle could prove more effective.

The most useful characteristic of optically noticeable oil is its characteristic absorption spectrum. Measurements performed elsewhere (Reference 5) had confirmed earlier observations (Reference 6) that oils are effectively opaque in the near-ultraviolet (UV) region of the spectrum. Pure, freshly distilled mineral oil of pharmaceutical quality is transparent at this wavelength, but quickly becomes opaque upon exposure at an air-water interface. In addition, commercial grades of oils are colored by impurities and are opaque in the wavelength region from 300 to 400 nanometers. In the 600 nm region of the spectrum, however, thin films of most of these oils are fairly transparent (Figure 9). Oil films in the thickness range from one micron to one millimeter can therefore be detected, even in the presence of partially opaque debris, for example silt, by a differential transmissometer which compares transmission at 360 nm (near UV) with that at 600 nm (orange-red) wavelengths. Weak light sources in the orange-red region of the spectrum, useful for a remote, battery-powered transmissometer, are plentiful. It is difficult, however, to find an efficient (i.e., low-power, rugged, and inexpensive) source of near-UV radiation.

The most practical source is the argon glow discharge bulb, but its finite life (50...3000 hours) presents problems. The useful life of an argon glow discharge bulb appears to be terminated by the deposit of a thin metal layer on the bulb surface by sputtering which proceeds with alacrity in an argon atmosphere. Bulbs with an extraordinary life were made by exciting the glow discharge with a small RF oscillator in an electrodeless bulb (Reference 7), but it was found that infrared emissions from the discharge were much more prevalent in this lamp than in the conventional cathode glow lamp. This problem could be overcome by using optical filters. Filters which pass the near ultraviolet but not the near infrared are quite rare. After extensive effort, only one such filter with a considerable attenuation at 360 nm wavelength was found. Near-UV radiation can also be obtained from mercury discharge lamps with a conversion phosphor (Reference 6), but considerable power and control of the envelope temperature is needed for their operation. In addition, the mode of operation which proved most useful for the differential transmissometer required restarting at one second intervals which is difficult with fluorescent bulbs.

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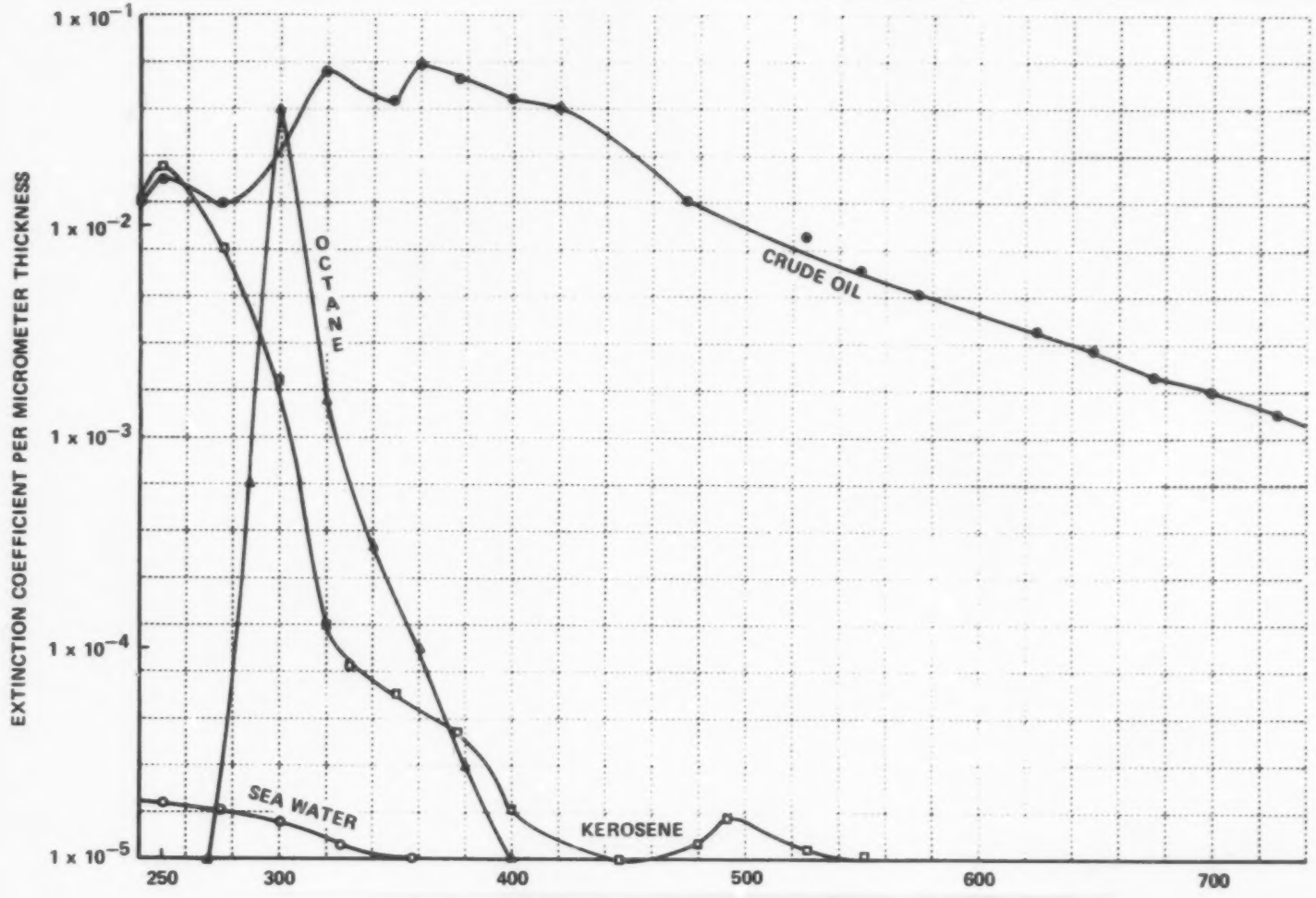

Figure 9 NEAR-VISIBLE ABSORPTION SPECTRA OF COMMON OIL POLLUTANTS

NEAR-ULTRAVIOLET OIL SENSOR

The transmissometer used as an unattended, battery-operated, oil sensor took the general form shown in Figure 10. A circuit diagram is shown in Figure 11. A neon discharge bulb (GE Ne-48) and an argon discharge bulb (GE AR-3) were flashed in succession by application of a 150 Volt, 2000 Hz alternating voltage through a suitable dropping resistor. DC excitation was not used because it resulted in local cleaning of the electrodes with resultant wander of the discharge and unsteady light output in a given direction. The output of the bulbs, which are directly exposed to sewage, was sensed by a fairly linear cadmium sulfide photoresistor (Clairex 705 HL) after passage through either a surface layer, or 2 cm of oil emulsified with sewage. The output of the photocell was applied to a varactor which shifted the frequency of the crystal oscillator of a citizen's band transmitter. The maximum frequency shift of about 400 Hz was well within the carrier frequency tolerance limits for this type of service and permitted short (30-second), hourly transmissions of oil concentration with a minimum of interference to and from hobbyists.

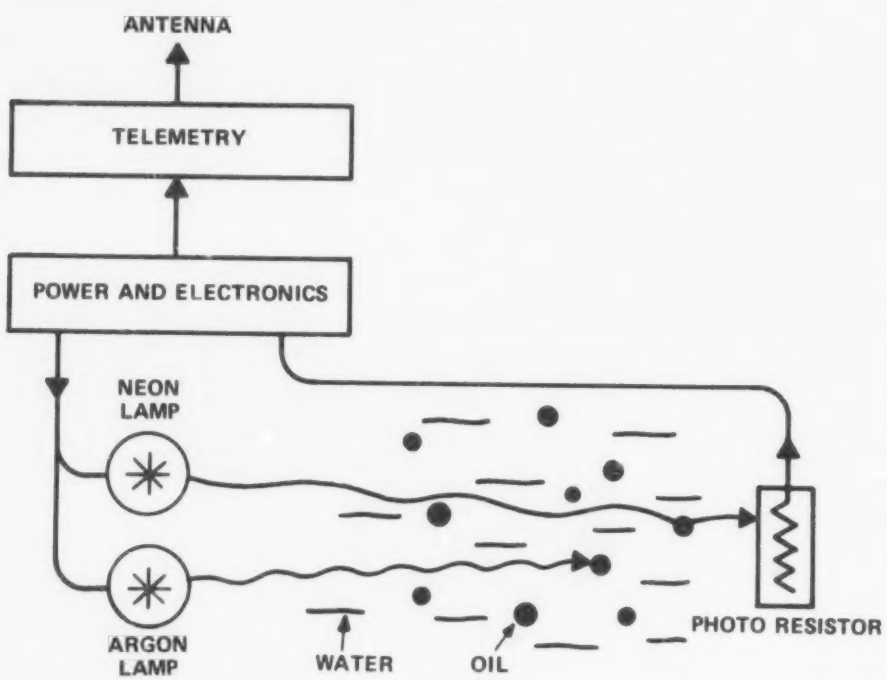

Figure 10 NEAR-ULTRAVIOLET OIL SENSOR

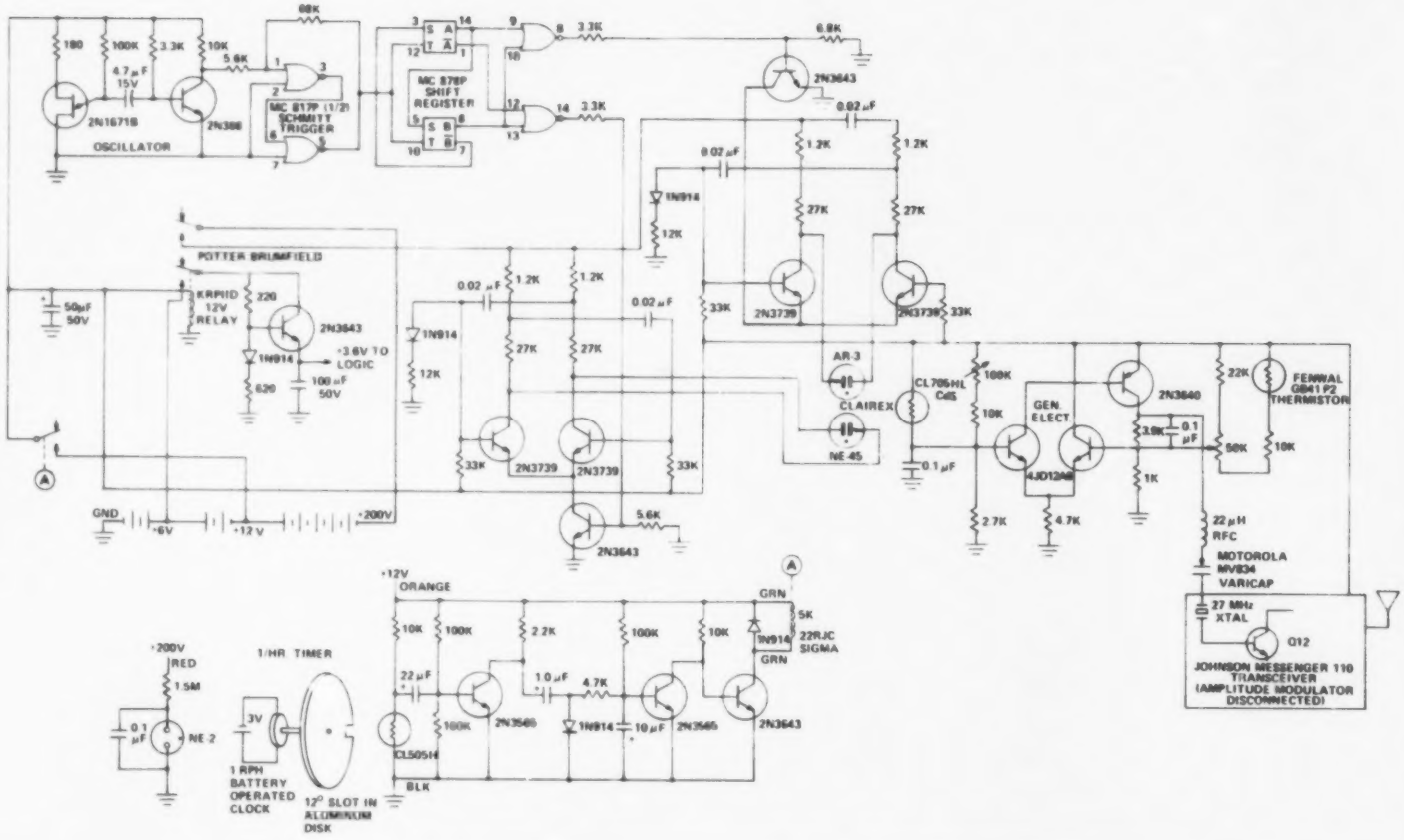

Figure 11 SCHEMATIC OF ULTRAVIOLET SYSTEM

The transmissometer, with its battery power supply, timers, and transmitters, was installed in a 55 gallon drum largely filled with concrete to discourage vandalism. For purposes of evaluation, the device was set near an off-road manhole which connected to an oil-polluted sewer (Figure 12). Oil in this sewer is believed to come from a railroad yard. Leaching of calcium carbonates from the limestone constituting the road bed of this yard resulted in coating of the optical components by scale which has to be removed at intervals of one to several weeks. Leaves and pieces of cloth were occassionally wrapped around the apparatus but these could be excluded by a simple screen.

The instrument is calibrated in a chlorothene (1,1,1 trichloroethane) solution of oil. Initially the probe is submerged in a known quantity of fresh, presumably oil-free solvent. A slight relative attenuation of the ultraviolet transmission is noted at thie time. Oil is then added, first a drop at a time and then in quantites of several cubic centimeters, and the ratio of pulse height at the photo sensor, during the UV pulse to that observed during the orange pulse, is measured. Since this ratio remains unchanged in clean water, the readings (Figure 13) should be normalized to the ratio in fresh chlorothene, i.e., in an ideal water dispersion of oil one would expect to use the scale on the right of Figure 13.

Although calibration in water would have been more desirable, it is impractical since the oil used for calibration cannot be dispersed without adding some emulsifier. The emulsifier has an effect on transmission of both visible and UV light which is difficult to calibrate. In the sewers of interest here, flow is quite rapid and the oil is dispersed by turbulence. This is shown by the fact that almost all of the oil separates at the surface upon letting a sample stand for a few hours. Quantitative correlation of the instrument readings in the sewer with those in the chlorothene solution are thus not possible at this time, and the device is merely a relative oil concentration meter. Work on establishing a correlation by comparison of chemical assays and instrument readings continues.

CAPILLARY WAVE PROPAGATION

Other methods must be used to detect films thinner than a wavelength of light. Such films are common because of the abundance of oils, frequently of natural biological origin. Langmuir cells in the epilimnion of lakes have been observed by the wave damping effect of thin oil films due to diatoms long before man-made oil pollution became a problem (Reference 8). At the present time, most inland waters of the U.S.A. may be expected to carry at least a monomolecular film, and detection of such thin films is of secondary interest in connection with control of gross pollution. The effect of very thin oil films on the damping and propagation of capillary waves has been studied by numerous workers (Reference 9) under laboratory conditions. In most cases, optical techniques involving human observers or photography have been most appropriate for sensing this effect.

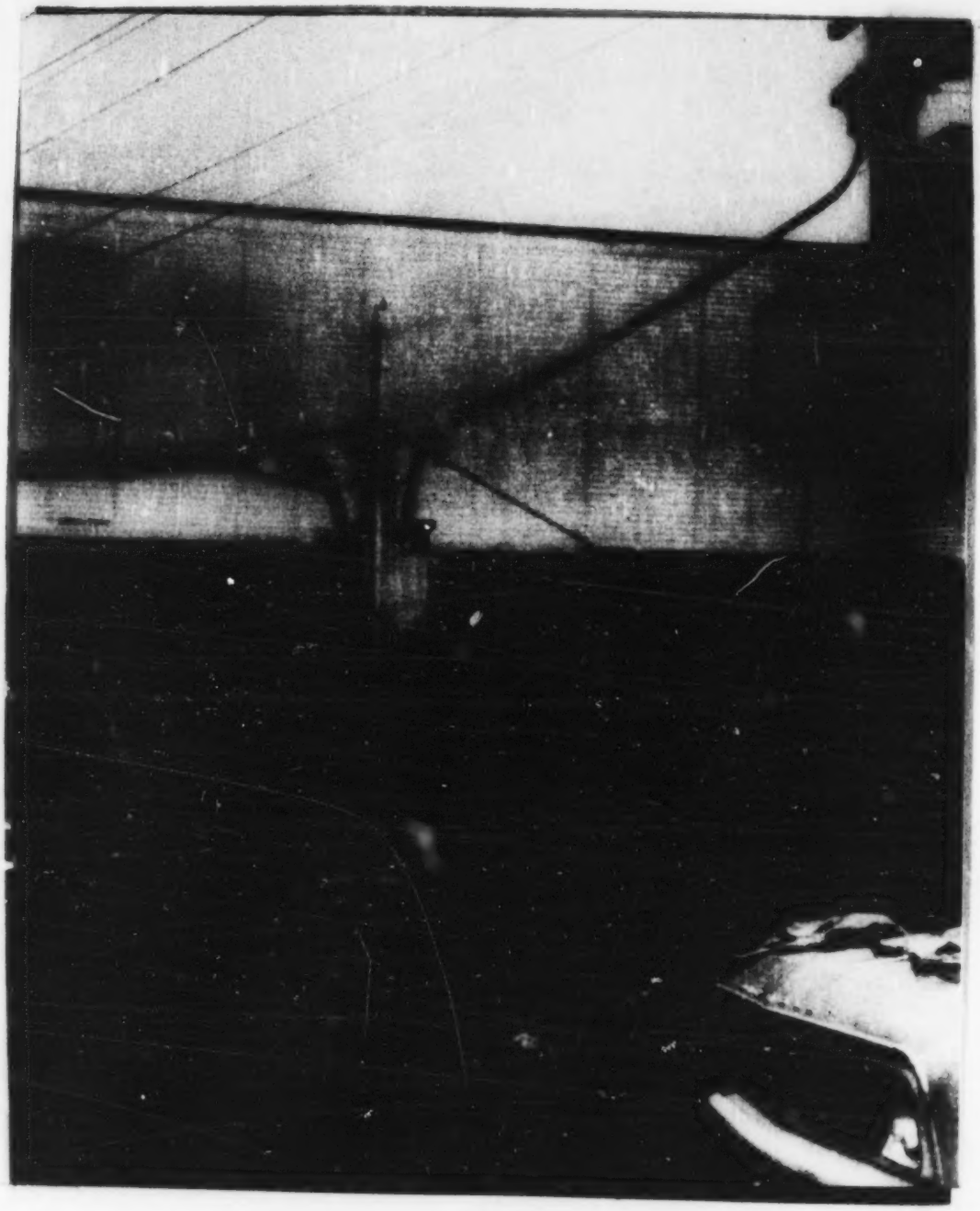

Figure 12 UV SENSOR INSTALLATION

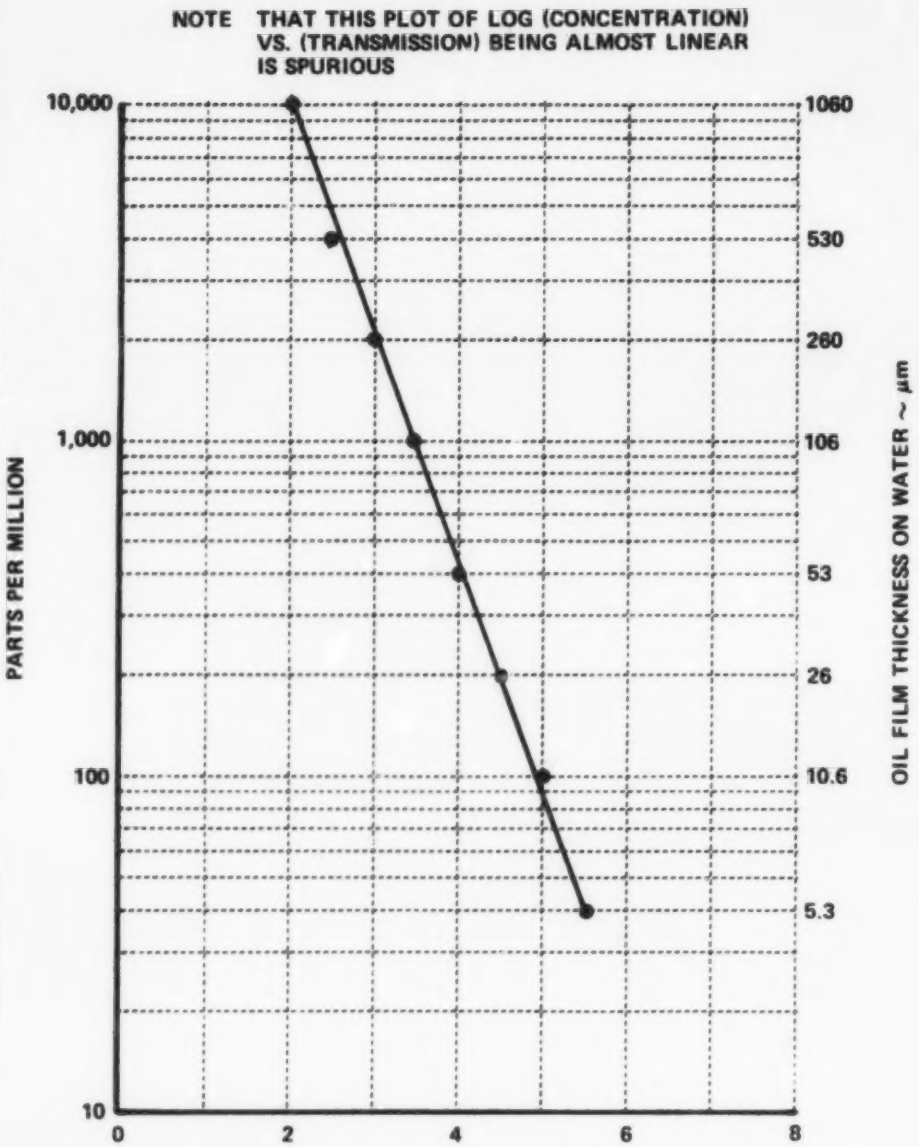

Figure 13 OIL IN CHLOROTHENE CALIBRATION

A device capable of remote unattended operation for sensing capillary wave propagation and thus, thin films of oil, might be useful under some conditions and a laboratory version of such a device was tested (Since this development was not directly applicable to the In-sewer Study, it was funded internally by Cornell Aeronautical Laboratory). A capillary wave transmitter, consisting of a loudspeaker which drives a wave generating wedge (Figure 14), is coupled to a wave detector, assembled from a ceramic phonograph pickup and a detector paddle, by a short (~10cm) path of water surface. The phase and amplitude of received waves was compared with the loudspeaker excitation. Low audio frequencies (40 to 120 Hz) were used to drive the speaker. Direct acoustic propagation (through supports) had to be attenuated by padding and flexible supports for the sensor.

The preparation of thin oil films proved difficult since miniscule quantities of oil adhering to the appartus tended to coat the water surface. Changes of about five percent in the propagation velocity could, however, be induced by dissolving these thin films with the addition of very small smounts of detergent.

On the basis of experience with this feasibility test it is concluded that this device should be capable of operation in open water if certain changes are made. The sensor assembly should be mounted in an S-shaped channel between catamaran hulls and the effect of residual, externally introduced waves should be minimized by frequency selectivitiy in the amplifiers following the capillary wave receiver.

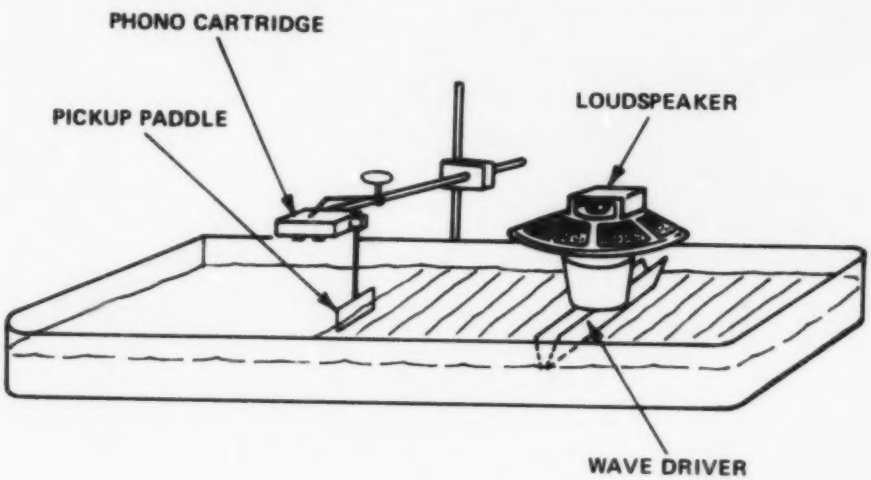

Figure 14 CAPILLARY WAVE PROPAGATION APPARATUS

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